Results from recent 30 GHz and X-band Accelerating Structure Tests

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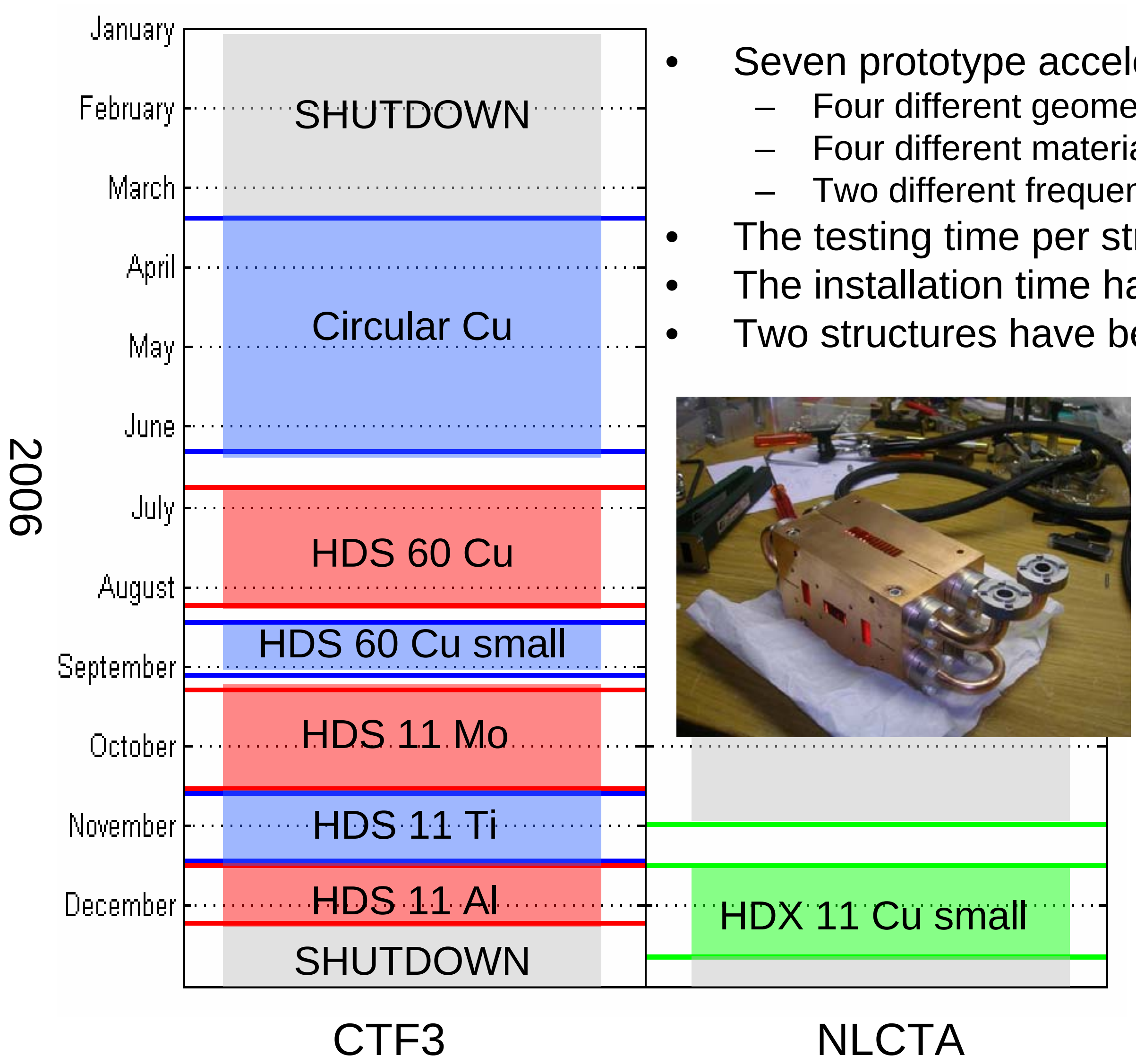
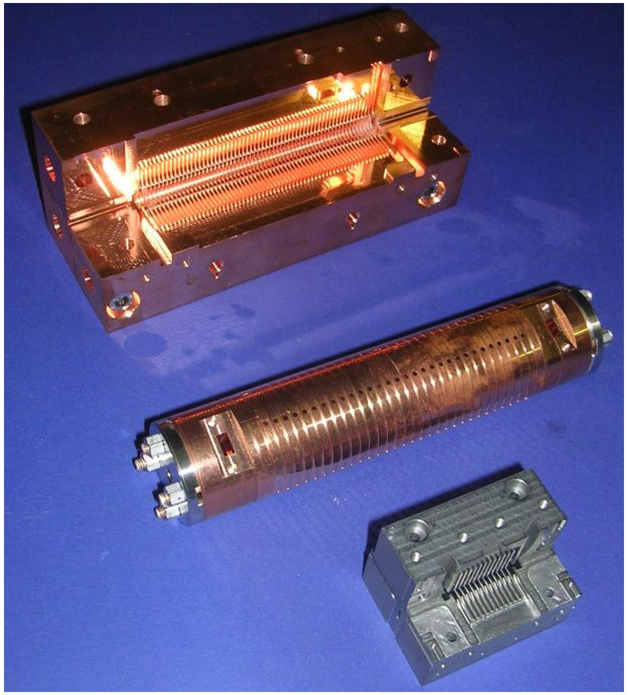
The Structures tested



- Seven prototype accelerating structures were tested:
  - Four different geometries (Circular, HDS 11,HDX 11, HDS 60)
  - Four different materials (Cu, Al, Ti, Mo)
  - Two different frequencies
- The testing time per structure has been reduced
- The installation time has also been reduced
- Two structures have been tested at the same time



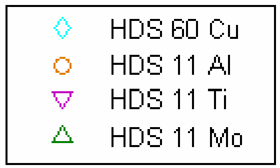
The Structures tested

	HDS 11	HDS 60	HDS 60 Small	HDX 11 Small
Assembly	Clamped Quadrants			
Number of cells	11	60	60	11
P_{INC} [MW] @ E_{1st} = 150 MV/m	98		54	370
$E_{SURFACE}$ [MV/m] @ E_{1st} = 150 MV/m	268		252	252
a [mm]	1.9		1.6	

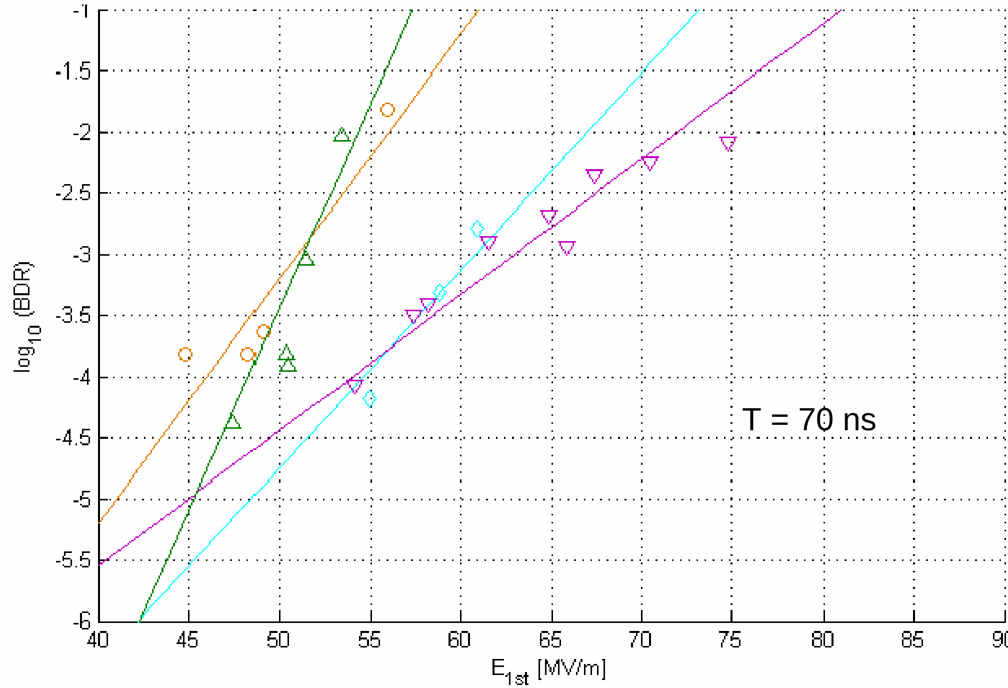
Other Structures Tested	
30 GHz	2 x Circular Mo
	1 x Circular W
	2 x Circular Cu
11.4 GHz	1 x Circular Mo
	1 x Circular W

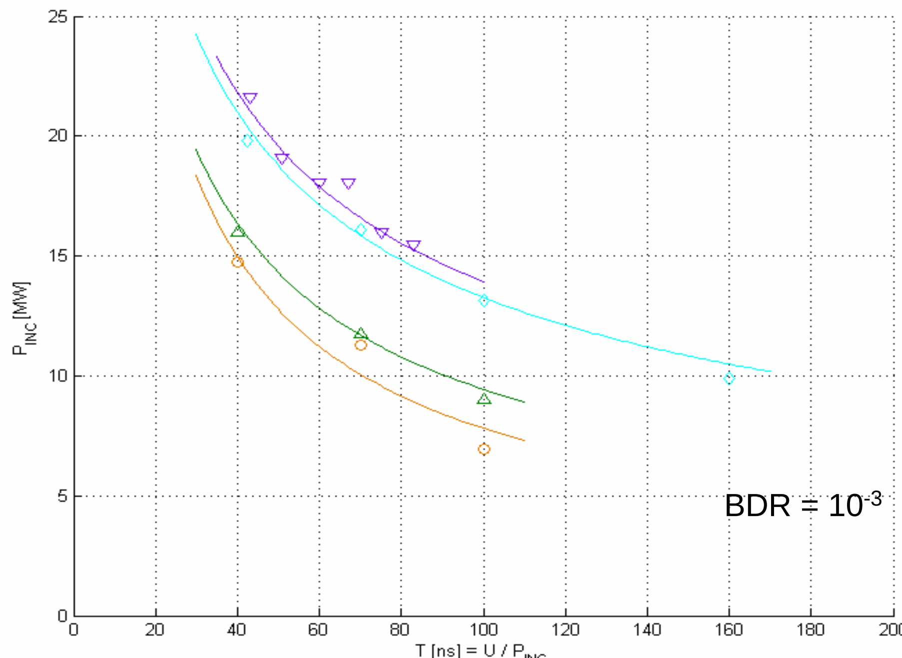
	Circular Structures @ 30 GHz
Assembly	Clamped or brazed cells
Number of cells	30
P_{INC} [MW] @ E_{1st} = 150 MV/m	54
$E_{SURFACE}$ [MV/m] @ E_{1st} = 150 MV/m	330
a [mm]	1.75

Material



	HDS 11 Ti	HDS 60 Cu	HDS 11 Mo	HDS 11 Al
E_{1st} [MV/m] @ 70ns, BDR=10^{-3}	63	61 (97%)	51 (81%)	51 (81%)
E_{1st} [MV/m] @ 70ns, BDR=10^{-6}	36	42 (117%)	42 (117%)	36 (100%)
P_{INC} / C [MW/mm] @ 70ns, BDR=10^{-3}	1.72	1.61 (94%)	1.13 (66%)	1.13 (66%)
P_{INC} / C [MW/mm] @ 70ns, BDR=10^{-6}	0.56	0.76 (136%)	0.76 (136%)	0.56 (100%)
Slope [MV/decade]	9.0	6.2	3.0	5.0
k in $P\,T^k$ = CTE	-0.49	-0.50	-0.60	-0.71





Material

• Slopes seem to be different for different materials

• Therefore, the relative performance of the different materials depends on the desired breakdown rate

• In particular at BDR = 10^{-3} (well characterized experimentally), Ti is the best performer

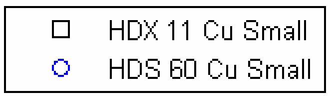
• The performance of Ti could be even better than shown (a degradation of the performance was observed while conditioning)

• A different material ordering was observed in other experiments (brazed circular copper, clamped circular molybdenum)

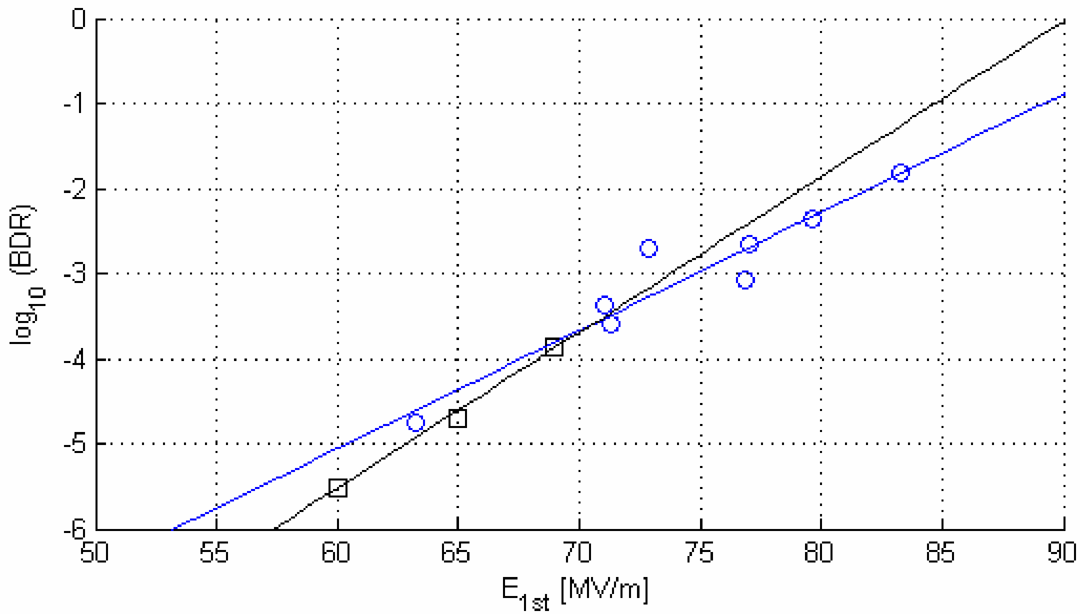
• The pulse length dependence seems to be stronger than the traditional 1/3 even for copper

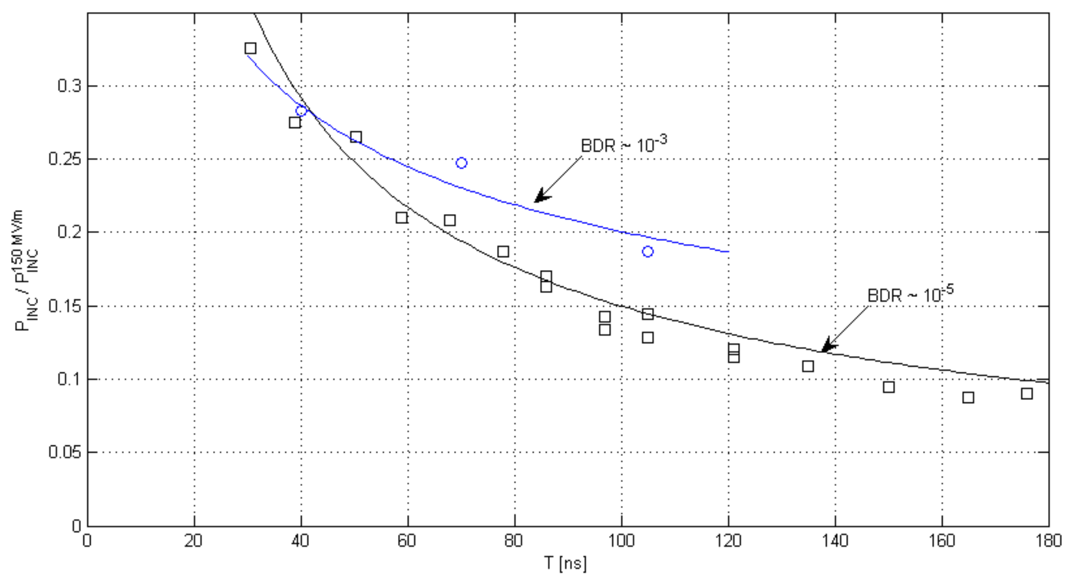
• The relative performance of the materials does not depend on the chosen pulse length (in the range it was measured)

Frequency



	HDS 60 Cu Small	HDX 11 Cu Small
E_{1st} [MV/m] @ 70ns, BDR=10^{-3}	75	74
E_{1st} [MV/m] @ 70ns, BDR=10^{-6}	53	57
Slope [MV/decade]	7.2	5.5
k in P T^k = CTE	-0.39	-0.73

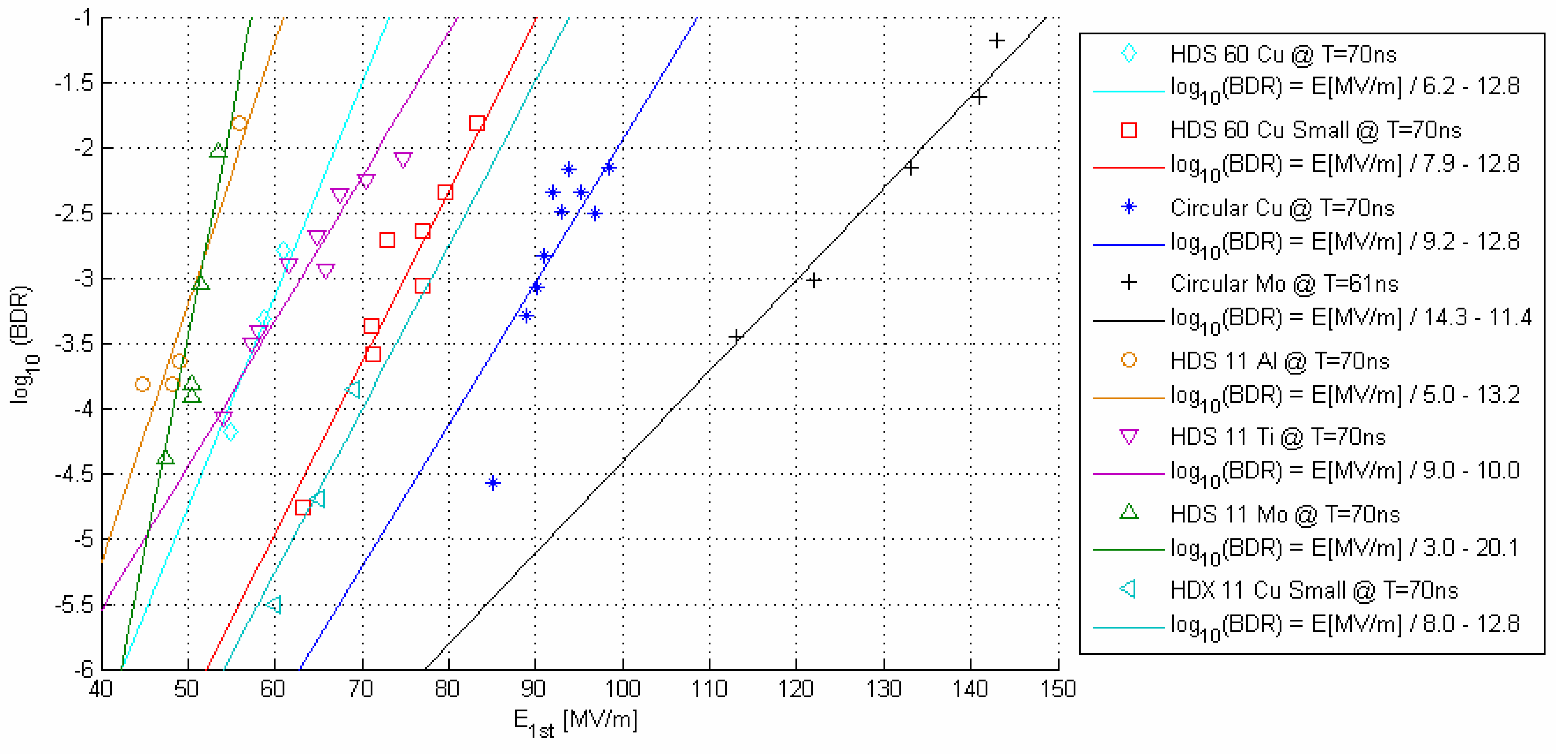




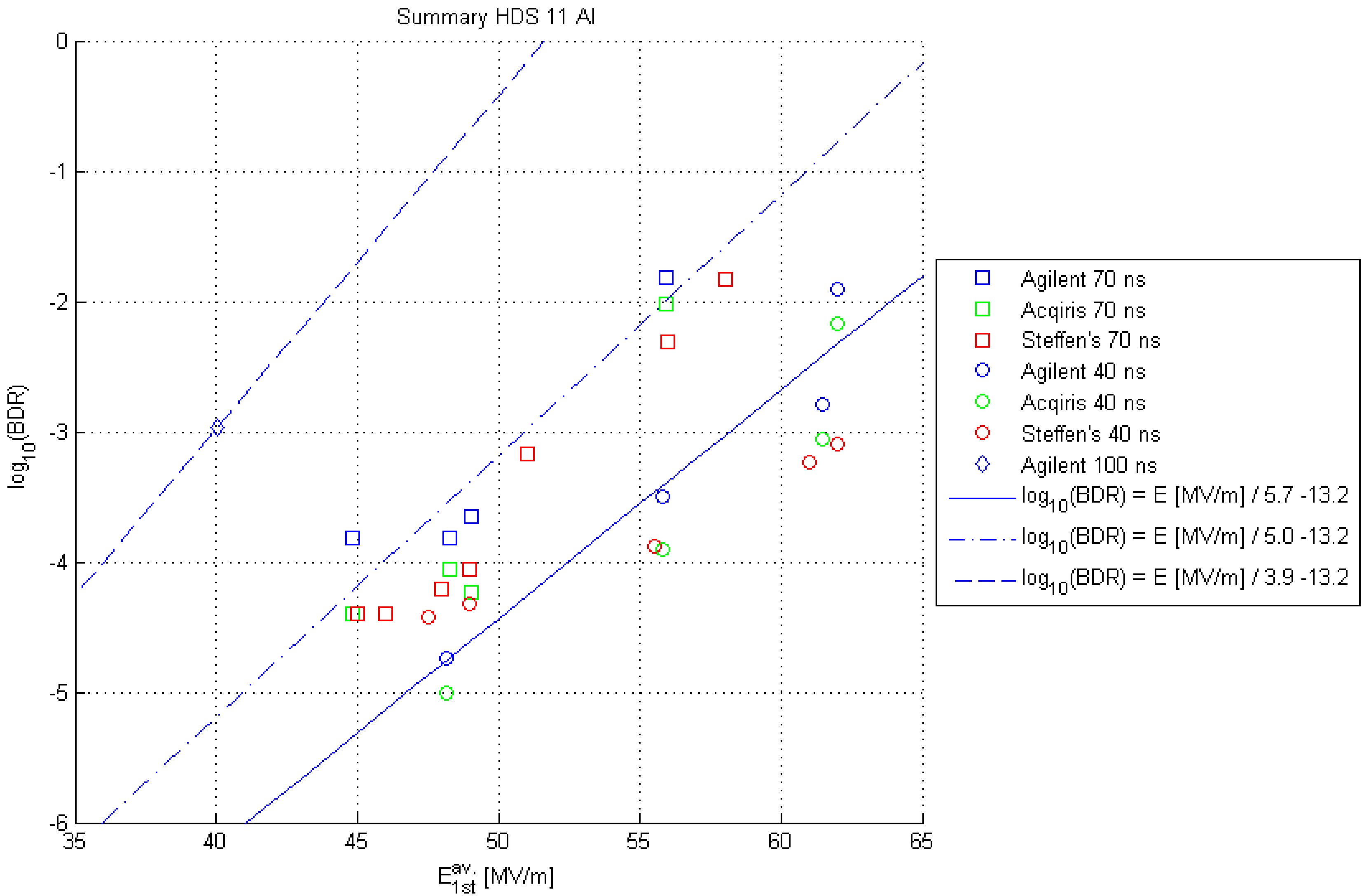
Frequency

- Slopes are similar in both structures
- Two other pairs of similar structures have been tested before at different frequencies
- The pulse length dependence seems to be the traditional 1/3 in the 30 GHz structure but steeper in the 11.4 GHz structure
- A degradation of the HDX structure was observed during the conditioning that could also explain the stronger than usual pulse length dependence

Breakdown rates @ 70 ns



HDS 11 Al: Breakdown rates



HDS 11 Al: Breakdown rates

With free linear dependence @ 70ns
Linear model Poly1:
f(x) = p1*x + p2
Coefficients (with 95% confidence bounds):
p1 = 0.1966 (-0.02601, 0.4193)
p2 = -13.02 (-24.08, -1.953)

Goodness of fit:
SSE: 0.3464
R-square: 0.8783
Adjusted R-square: 0.8175
RMSE: 0.4162

With free linear dependence @ 40ns
Linear model Poly1:
f(x) = p1*x + p2
Coefficients (with 95% confidence bounds):
p1 = 0.1789 (0.02305, 0.3348)
p2 = -13.41 (-22.31, -4.5)

Goodness of fit:
SSE: 0.3266
R-square: 0.9242
Adjusted R-square: 0.8863
RMSE: 0.4041

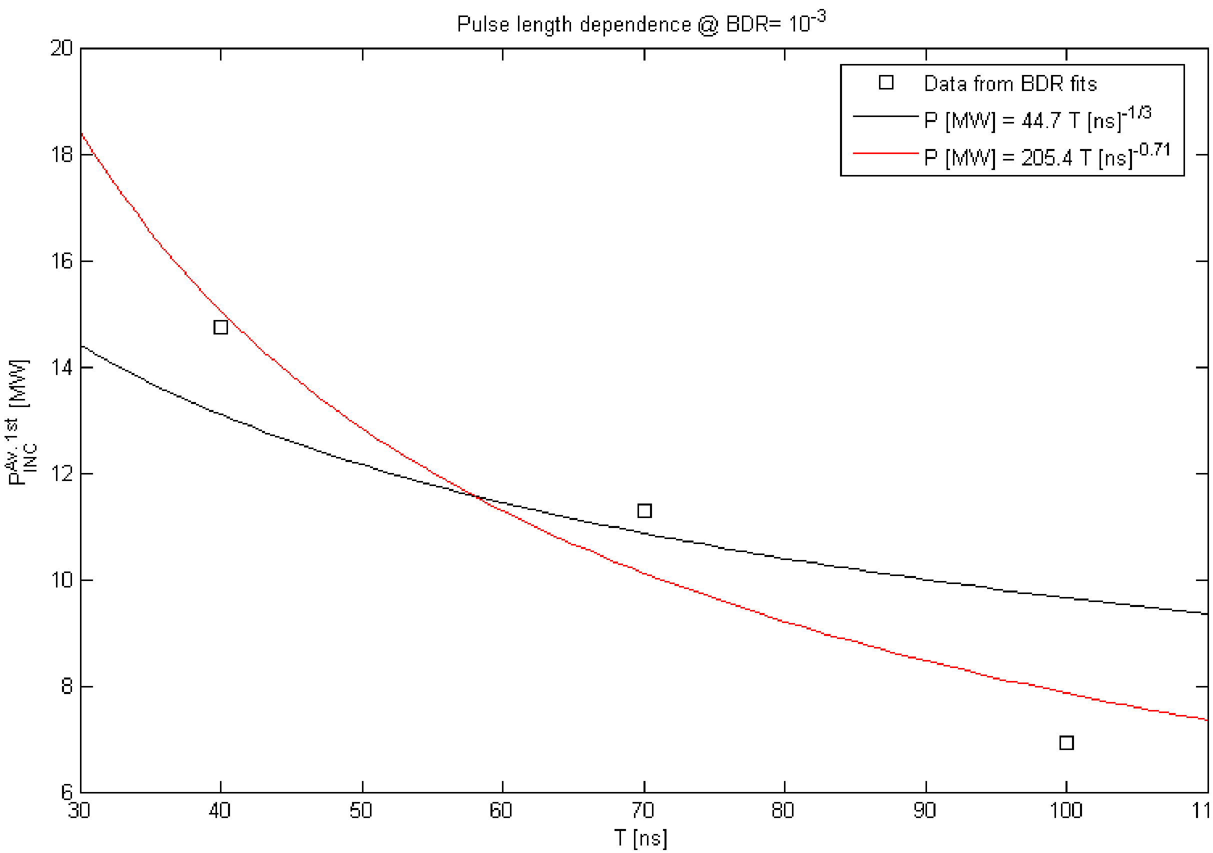
With fixed (to the average of the two free fits) linear dependence @ 70ns
Linear model Poly1:
f(x) = p1*x + p2
Coefficients (with 95% confidence bounds):
p1 = 0.2006 (0.1897, 0.2115)
p2 = -13.22 (fixed at bound)

Goodness of fit:
SSE: 0.3475
R-square: 0.878
Adjusted R-square: 0.878
RMSE: 0.3403

With fixed (to the average of the two free fits) linear dependence @ 40ns
Linear model Poly1:
f(x) = p1*x + p2
Coefficients (with 95% confidence bounds):
p1 = 0.1756 (0.1664, 0.1848)
p2 = -13.22 (fixed at bound)

Goodness of fit:
SSE: 0.3279
R-square: 0.9239
Adjusted R-square: 0.9239
RMSE: 0.3306

HDS 11 Al: Pulse length dependence



HDS 11 Al: Pulse length dependence

<u>With fixed power dependence 1/3</u>

General model Power1:

    f(x) = a*x^b

Coefficients (with 95% confidence bounds):

    a =   44.72 (22.46, 66.99)
    b =   -0.333 (fixed at bound)

Goodness of fit:

  SSE: 10.25

  R-square: 0.6648

  Adjusted R-square: 0.6648

  RMSE: 2.263

<u>With free power dependence</u>

General model Power1:

    f(x) = a*x^b

Coefficients (with 95% confidence bounds):

    a =   205.4 (-2026, 2437)
    b =   -0.7086 (-3.427, 2.01)

Goodness of fit:

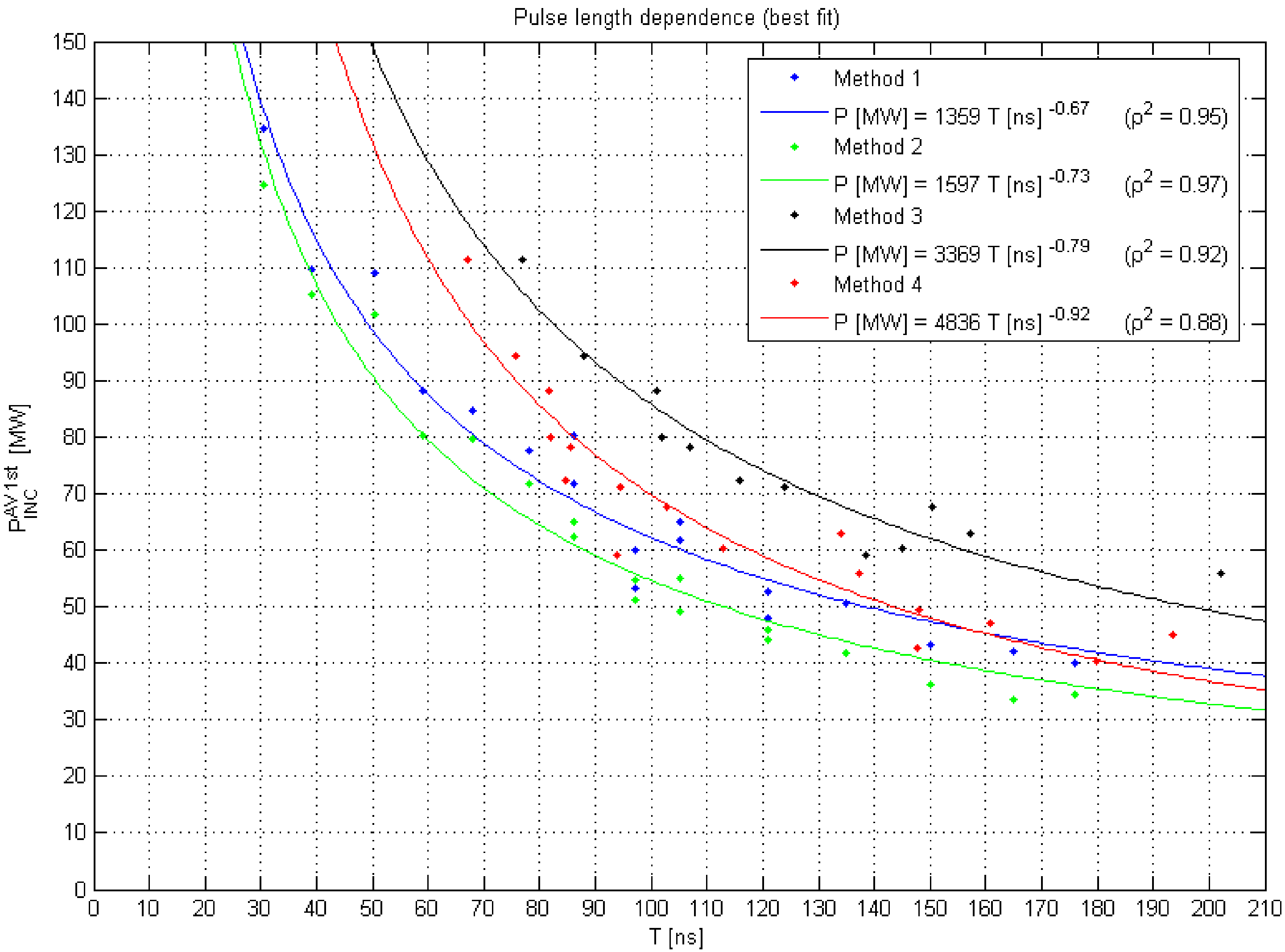
  SSE: 2.322

  R-square: 0.924

  Adjusted R-square: 0.8481

  RMSE: 1.524

HDX 11 Cu: Pulse length dependence



Pulse length dependence measurements Description of different measurements

- Tscope_1, Vmax_1, Vtop_1:

  - The pulse length (Tscope_1) was changed from 30.5 ns to 176 ns. Note that all the pulse lengths used are those automatically measured by the scope in the control room.

  - For each pulse length, the power was slowly ramped up until a breakdown occurred (typically it took ~ 1 minute each time the power was ramped up).

  - At that point, the power was reduced without changing the pulse length and after waiting for 20 seconds before putting power in the structure.

  - This process was repeated for 15 minutes without taking any data.

  - Afterwards, five more ramp ups were performed writing down the maximum power read by the peak power meters (Vmax, Vtop)

  - Vmax_1 and Vtop_1 are the maximum values read by the peak power meters in those five ramp ups.

- Tscope_2, Vmax_2, Vtop_2:

  - Vmax_2 and Vtop_2 are the average values read by the peak power meters in the five ramp ups described before.

- Tscope_3, Vmax_3, Vtop_3:

  - The power (Vtop_3) was changed from 54.5 MW to 134.5 MW. Note that the lowest power was defined by the maximum pulse length reachable without deteriorating the pulse shape (~200 ns).

  - For each power, the pulse length was ramped up until a breakdown occurred (typically it took ~ 1 minute each time the pulse length was ramped up).

  - At that point, the pulse length was reduced without changing the power and after waiting for 20 seconds before putting power in the structure.

  - This process was repeated for 15 minutes without taking any data.

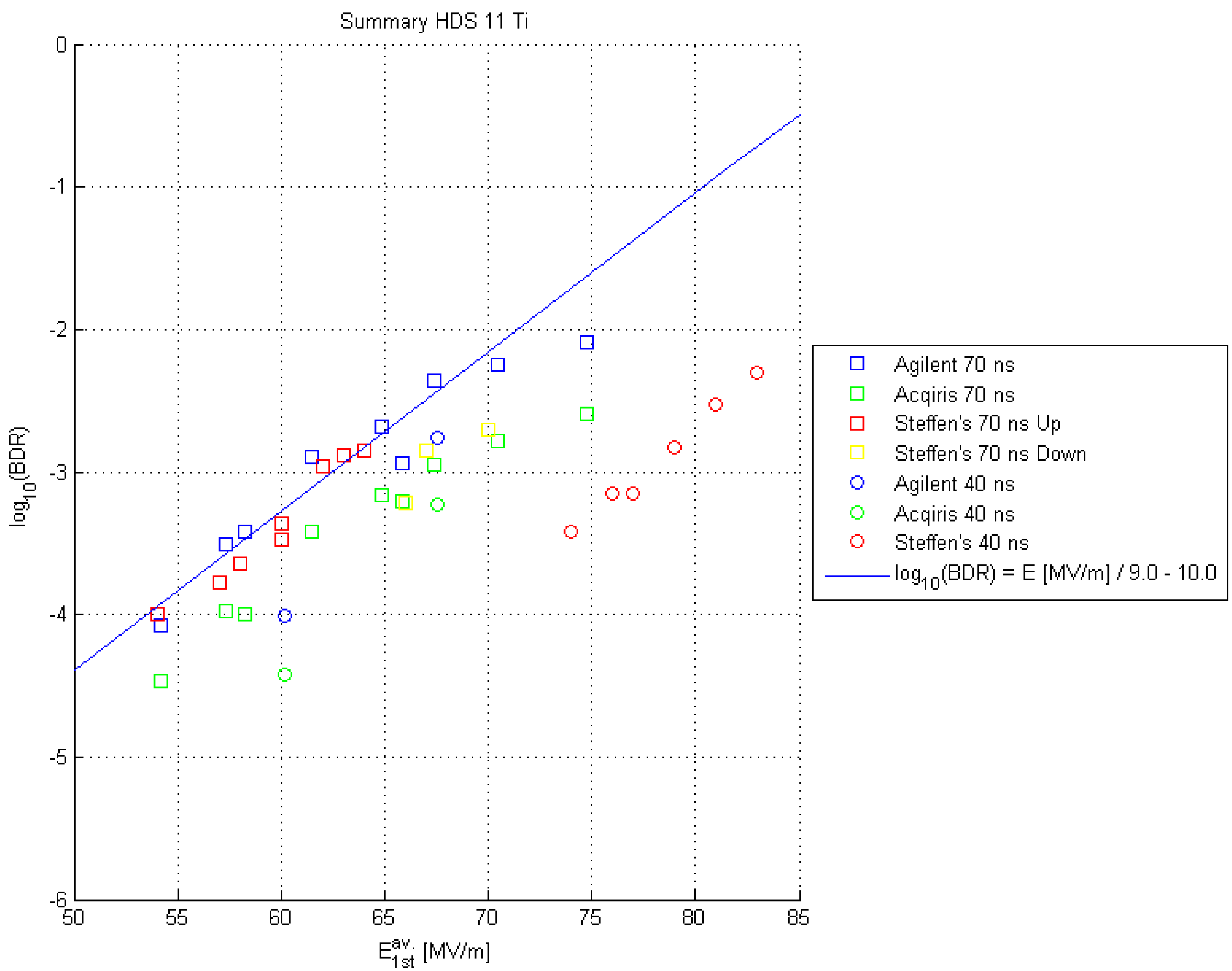
  - Afterwards, ten more ramp ups were performed writing down the maximum pulse length read by the scope (Tscope)

  - Tscope_3 is the maximum value read in those ten ramp ups.

- Tscope_4, Vmax_4, Vtop_4:

  - Tscope_4 is the average value read in the ten ramp ups described before.

HDS 11 Ti: Breakdown rates



HDS 11 Ti: Breakdown rates

<u>With free linear dependence and excluding the two points with the highest BDR @ 70ns</u>

Linear model Poly1:

f(x) = p1*x + p2

Coefficients (with 95% confidence bounds):

p1 = 0.1114 (0.07064, 0.1522)

p2 = -9.956 (-12.46, -7.448)

Goodness of fit:

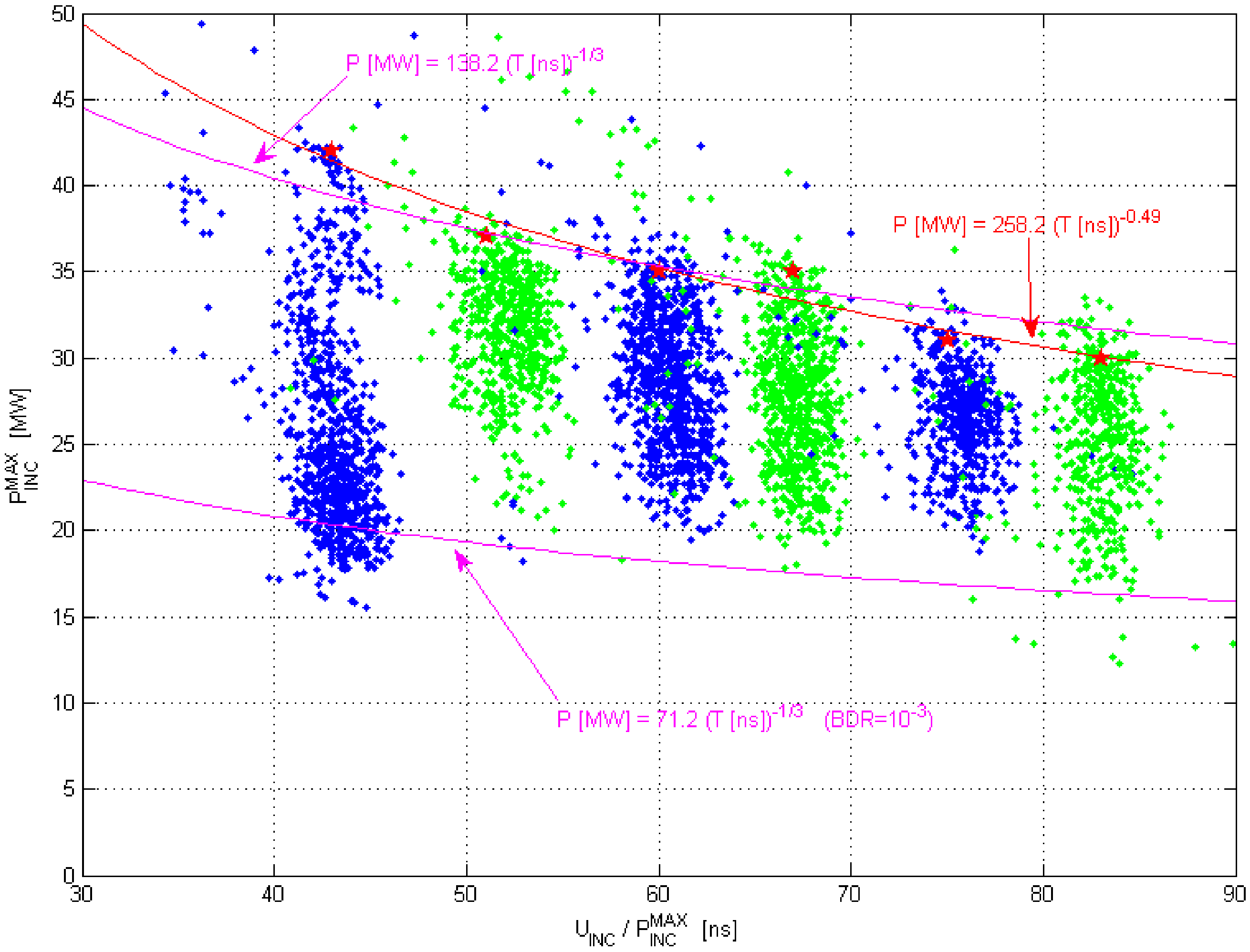
SSE: 0.1845

R-square: 0.908

Adjusted R-square: 0.8896

RMSE: 0.1921

HDS 11 Ti: Pulse length dependence



HDS 11 Ti: Pulse length dependence

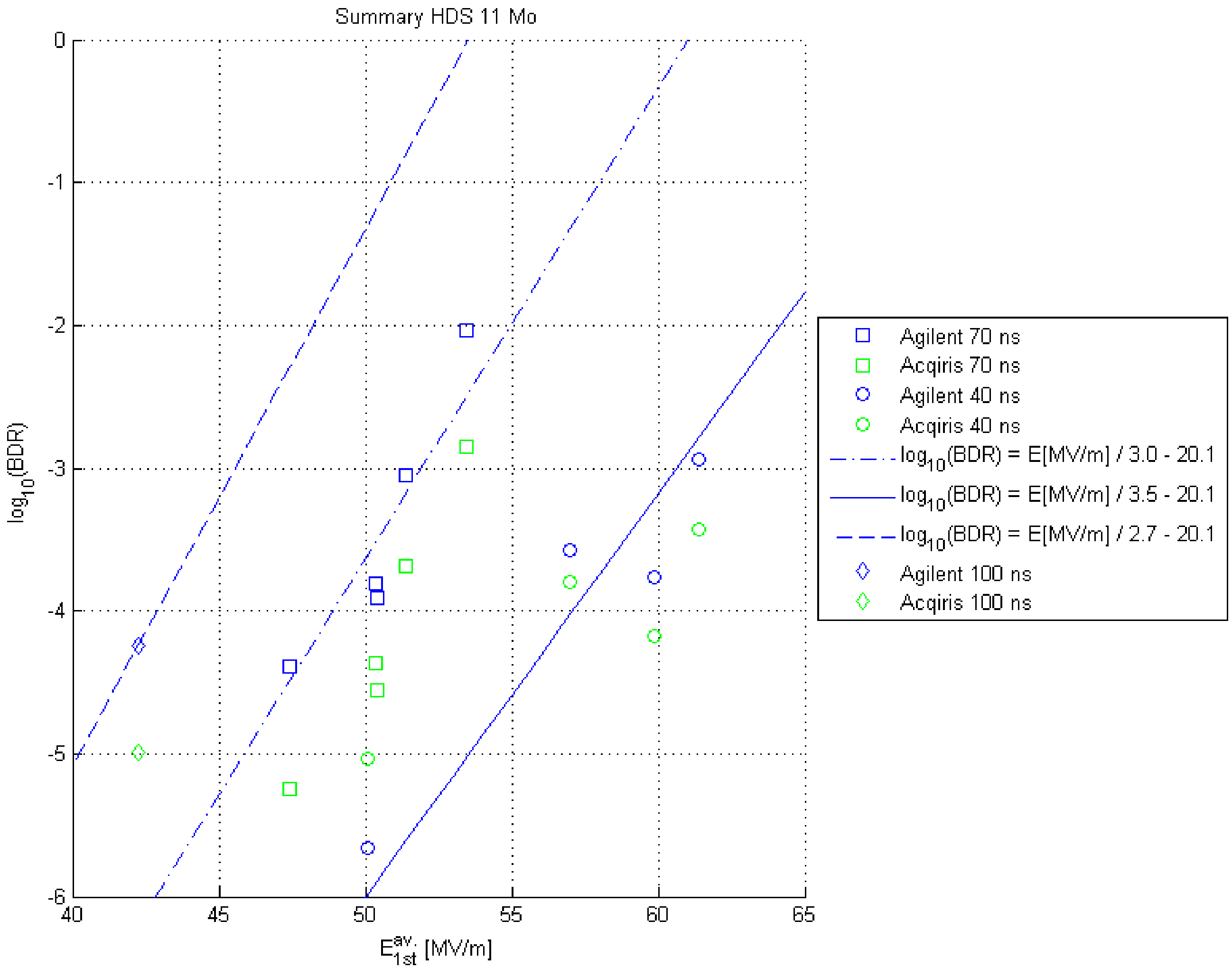
<u>With fixed power dependence 1/3</u>
General model Power1:
    f(x) = a*x^b
Coefficients (with 95% confidence bounds):
    a = 138.2 (131.4, 145)
    b = -0.3333 (fixed at bound)

Goodness of fit:
  SSE: 13.59
  R-square: 0.8554
  Adjusted R-square: 0.8554
  RMSE: 1.649

<u>With free power dependence</u>
General model Power1:
    f(x) = a*x^b
Coefficients (with 95% confidence bounds):
    a = 258.2 (97.9, 418.6)
    b = -0.4864 (-0.6386, -0.3341)

Goodness of fit:
  SSE: 4.621
  R-square: 0.9508
  Adjusted R-square: 0.9386
  RMSE: 1.075

HDS 11 Mo: Breakdown rates



HDS 11 Mo: Breakdown rates

With free linear dependence @ 70ns
Linear model Poly1:
f(x) = p1*x + p2
Coefficients (with 95% confidence bounds):
p1 = 0.3984 (0.129, 0.6678)
p2 = -23.6 (-37.25, -9.957)

Goodness of fit:
SSE: 0.4041
R-square: 0.8807
Adjusted R-square: 0.8409
RMSE: 0.367

With free linear dependence @ 40ns
Linear model Poly1:
f(x) = p1*x + p2
Coefficients (with 95% confidence bounds):
p1 = 0.2224 (0.009202, 0.4355)
p2 = -16.68 (-28.88, -4.474)

Goodness of fit:
SSE: 0.3726
R-square: 0.9097
Adjusted R-square: 0.8645
RMSE: 0.4316

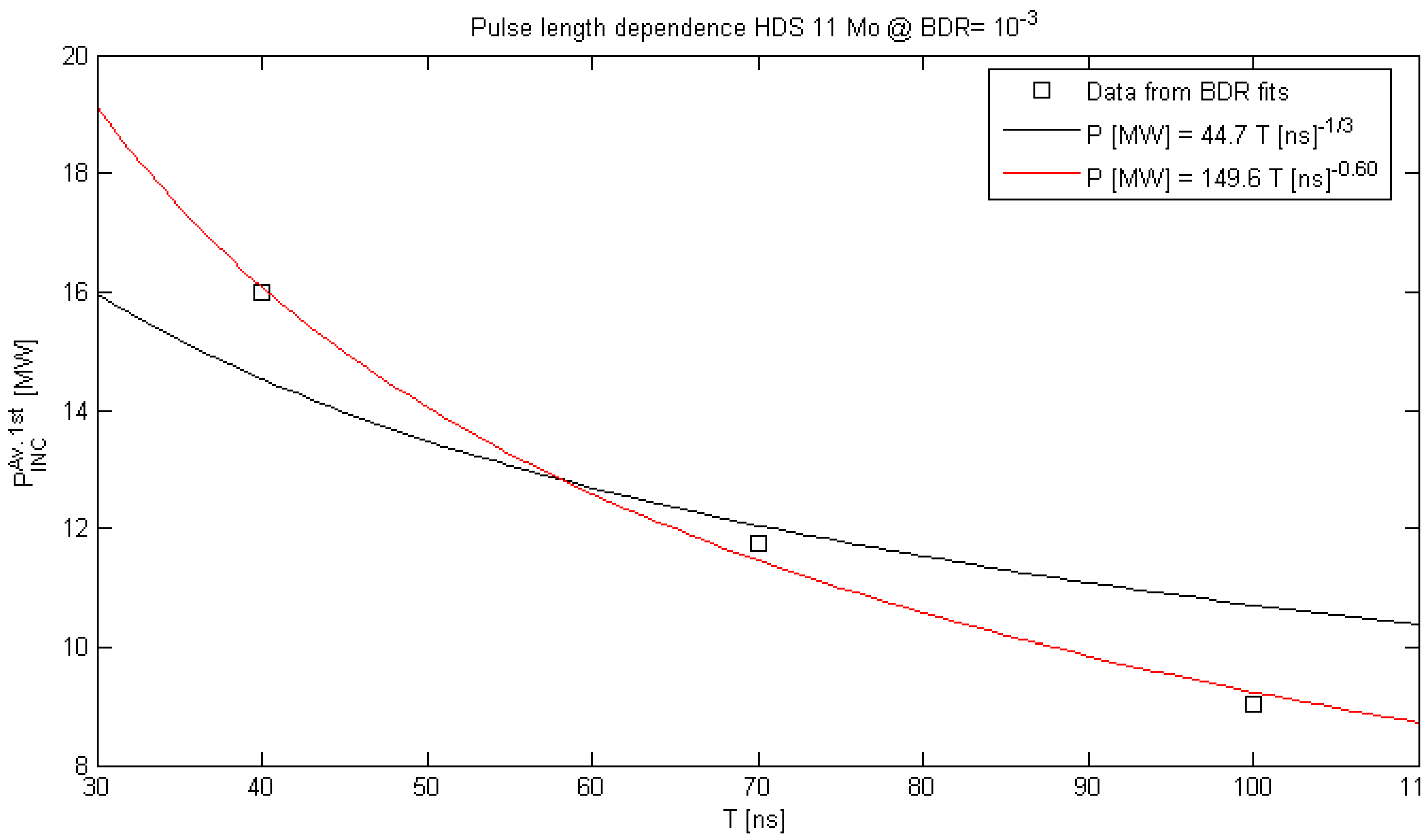
With fixed (to the average of the two free fits) linear dependence @ 70ns
Linear model Poly1:
f(x) = p1*x + p2
Coefficients (with 95% confidence bounds):
p1 = 0.3301 (0.3215, 0.3387)
p2 = -20.14 (fixed at bound)

Goodness of fit:
SSE: 0.4919
R-square: 0.8548
Adjusted R-square: 0.8548
RMSE: 0.3507

With fixed (to the average of the two free fits) linear dependence @ 40ns
Linear model Poly1:
f(x) = p1*x + p2
Coefficients (with 95% confidence bounds):
p1 = 0.2827 (0.2698, 0.2956)
p2 = -20.14 (fixed at bound)

Goodness of fit:
SSE: 0.6503
R-square: 0.8424
Adjusted R-square: 0.8424
RMSE: 0.4656

HDS 11 Mo: Pulse length dependence



HDS 11 Mo: Pulse length dependence

<u>With fixed power dependence 1/3</u>

General model Power1:

f(x) = a*x^b

Coefficients (with 95% confidence bounds):

a = 49.66 (33.97, 65.36)

b = -0.3333 (fixed at bound)

Goodness of fit:

SSE: 5.078

R-square: 0.7946

Adjusted R-square: 0.7946

RMSE: 1.593

<u>With free power dependence</u>

General model Power1:

f(x) = a*x^b

Coefficients (with 95% confidence bounds):

a = 149.6 (-187.2, 486.5)

b = -0.6046 (-1.164, -0.04526)

Goodness of fit:

SSE: 0.1248

R-square: 0.9949

Adjusted R-square: 0.9899

RMSE: 0.3533